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CALIFORNIA EXPERIENCE WITH HORIZONTAL DRAINS FOR LANDSLIDE CORRECTION AND PREVENTION

By
T. W. Smith
Senior Materials and Research Engineer
Materials and Research Department
California Division of Highways
Sacramento, California

and

G. V. Stafford
Assistant Highway Engineer
Materials and Research Department
California Division of Highways
Sacramento, California

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T. W. Smith[1], A.M., A.S.C.E.
G. V. Stafford[2]

The California Division of Highways installed what is believed to have been the first horizontal drains for slope stabilization in 1939. Basically horizontal drains are holes or borings that are drilled into an embankment or cut face. They are on a slight plus grade and are usually cased with perforated or porous liners.

Since that first job in 1939 approximately 235,000 lineal feet of horizontal drain has been installed by State forces and several installations have been made on certain roads by contract during construction.

With the knowledge gained through the experience and study of the pioneers in this field, and the dissemination of this knowledge among the engineers, many agencies both public and privately owned have adopted horizontal drains. Since their use has become so widely accepted it seems timely to discuss the changes in methods of installation, development of equipment, engineering aspects, and the merits of horizontal drains as a means of slide or slipout correction or prevention in the light of these sixteen years of elapsed time and thousands of feet of drains installed.

Horizontal drains have served a useful purpose in the

[1]Senior Materials and Research Engineer, Materials and Research Department, California Division of Highways.
[2]Assistant Highway Engineer, Materials and Research Department, California Division of Highways.

construction and maintenance of highways in California. They have far more than paid their own way in the saving of construction and maintenance dollars. This word of caution, however: they are not the answer to all problems relating to slides and slipouts, nor should they be considered a substitute for good planning, design and construction.

Experience has shown that horizontal drains are effective under a wide variety of soils and geologic, topographic, climatic, and ground water conditions. Some drainage installations have been made that were completely effective, a few have been made that were not effective, and the remainder have been effective in various degrees. The majority of installations made by the Division of Highways falls in this latter category. Horizontal drains are frequently used in combination with other measures to prevent or correct slides and slipouts.

The use of horizontal drains for prevention or correction of conditions that produce slides can be discussed best in several rather broad phases. These phases are purpose, investigation, planning and installation, equipment, maintenance and effectiveness. The phases naturally overlap and in actual practice cannot be completely segregated.

Purpose

The principal function of horizontal drains is to remove subsurface water from hillsides, cut slopes and fills. They are used in an effort to prevent slides by correcting the conditions that cause slides in cut slopes or embankments in certain types of soil or rock formations. They perform this function by removing the subsurface water either from the mass of sliding soil or from its source in the adjacent area.

The removal of the subsurface water tends to produce a more stable condition in several ways. The seepage forces are reduced. These seepage forces are not necessarily in the direction of sliding, but in general they would be far more detrimental than beneficial. Removal of the subsurface water tends to increase the shear strength of the soil. Cohesive soils that have a very high shear strength in a relatively dry state may have almost negligible shear strength in a saturated condition. This is especially true of plastic soils in fissures or in planes that have been weakened by previous movement. Removal of the subsurface water reduces any excess hydrostatic pressures that develop. Associated with excess hydrostatic pressures there is a loss in normal forces and hence a loss in frictional shear strength. Thus, a reduction in excess hydrostatic pressure causes a restoration or an increase in the frictional shear strength.

Investigation

The earliest phase of the necessary investigation that should precede the installation of horizontal drains should usually consist of a field review of the site to evaluate the conditions that are causing or tending to cause a slide or slipout. During this phase various methods of correction or treatment are considered. These methods may include horizontal drains. The people making the field review should be competent engineers or geologists who are familiar both with the causes of slides and slipouts, and the various methods of evaluating these causes. They should also have knowledge of various means which might be used to correct or improve the conditions.

The second step in the investigation frequently consists of geologic investigations, and/or exploratory borings, either vertical or horizontal. Generally, it is advantageous to have vertical boring data prior to the installation of horizontal drains. However, there are many instances where horizontal drains can be used for exploration purposes. In these instances the necessary soil and geologic data may be obtained and, at the same time, the holes may serve the more practical purpose of drainage.

The exploration should provide information on soils and geologic conditions as well as information on ground water conditions. In the installation of horizontal drains, it is important to know the location of the ground water and also the character of the material in which this water might be intercepted.

In vertical borings, once water is encountered, it is frequently very difficult to determine whether the entire soil stratum beneath is saturated or if there are layers of "perched" water. This information is important in installing horizontal drains and frequently it can be obtained with exploratory horizontal drains.

Planning and Installation

The first step in planning a horizontal drain installation is a careful analysis of the information available from field reviews, geologic investigation, borings, ground water studies, maps - including contours and sections, and all available data on construction and previous soil movement in the immediate vicinity. It should be emphasized that this phase of the work requires experience, sound judgment, and ingenuity.

The location and depth of the ground water, together with the topography will determine the locations from which the drains will be started. Since the drains will remove the water from the area by gravity, the starting point for a drain must be below the elevation of the point where water is to be intercepted. An exception to this idea would be the relief of excess hydrostatic pressure by a combination of vertical wells and horizontal drains. (Figs. 1, 2 & 3).

The spacing of the drains should be dependent upon the drainage characteristics of the soil, the quantity of water intercepted, and the character and magnitude of the slide involved. In drilling from any one elevation, usually drains are planned at intervals of 25 to 100 feet. Drains spaced with intervals of 100 feet would seldom provide adequate drainage, but would determine whether water could be intercepted. If large quantities of water exist it is frequently necessary to space the drains at intervals of less than 25 feet. Drains are often installed from more than one level if the terrain permits and the distances are such that the subsurface water can be reached from various levels.

The depths to which the drains are made are controlled by several factors. Perhaps the primary factor is the depth to which the drains must extend to contact the water bearing strata and properly drain the area and produce a stable condition in the slide. Other factors that may actually control the depths are difficulty of drilling, quantity of water drained, the economy and effectiveness of a greater number of shorter drains compared with fewer, but longer drains, and occasionally some other factors. The California Division of Highways have installed drains of various depths from 50 to in excess of 300 feet. Most of the drains have been between 100 and 200 feet long.

The grades on which the holes are drilled are largely determined by the topography and the ground water conditions. The drains must of necessity start from some point that can be

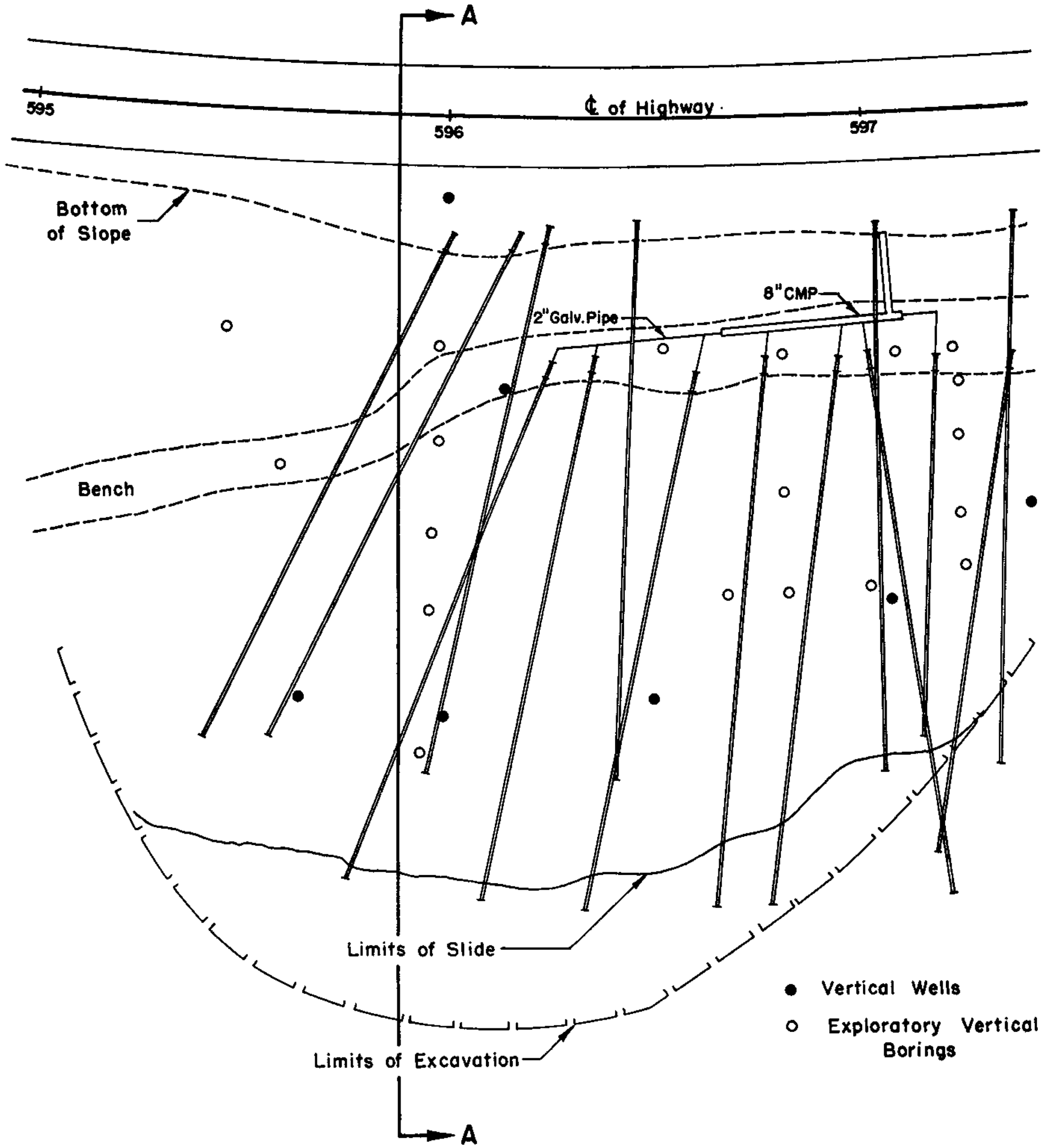

FIG. I SLIDE CORRECTION

HORIZONTAL DRAINS IN COMBINATION WITH VERTICAL DRAIN WELLS

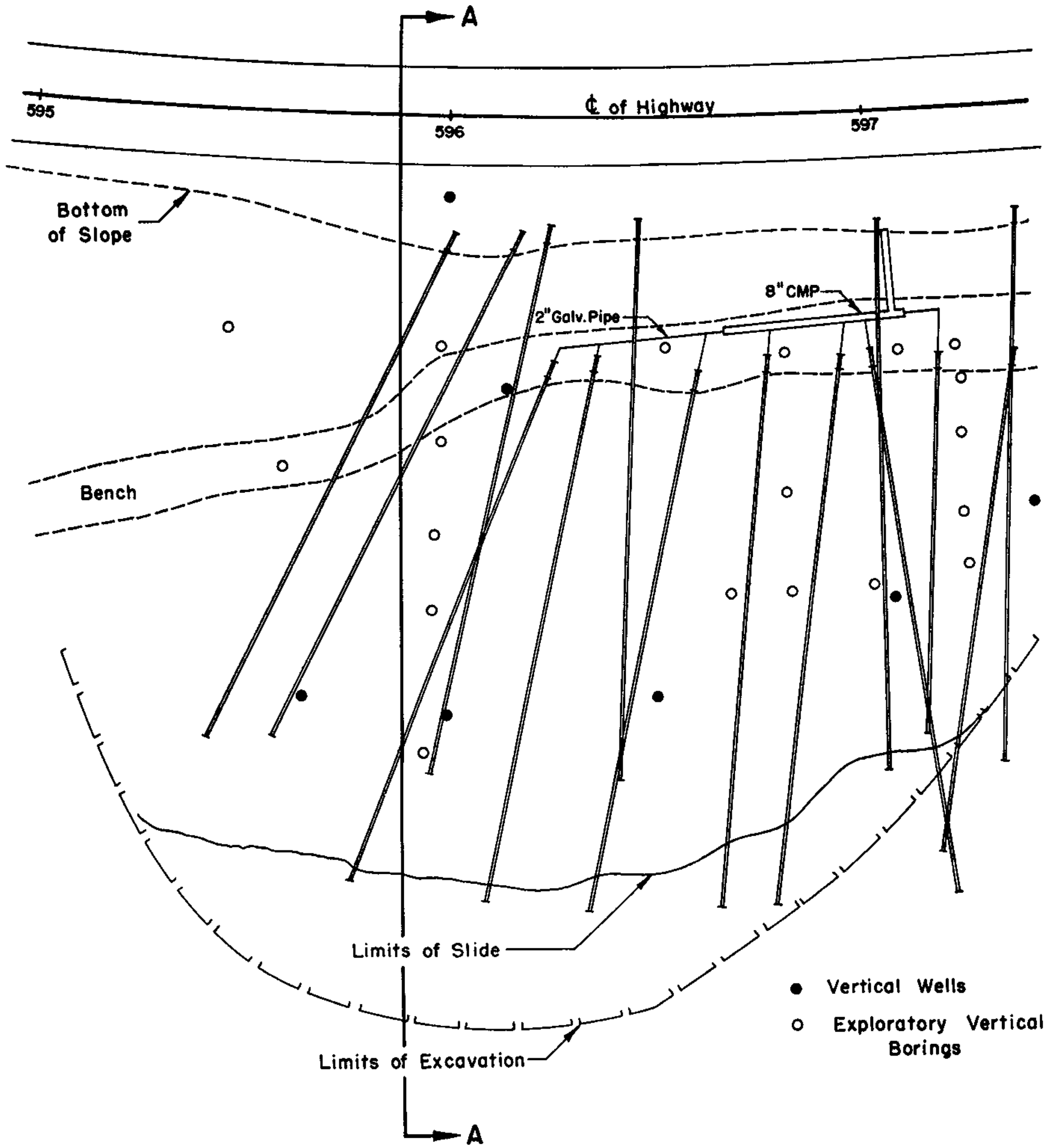

FIG. I SLIDE CORRECTION

HORIZONTAL DRAINS IN COMBINATION WITH VERTICAL DRAIN WELLS

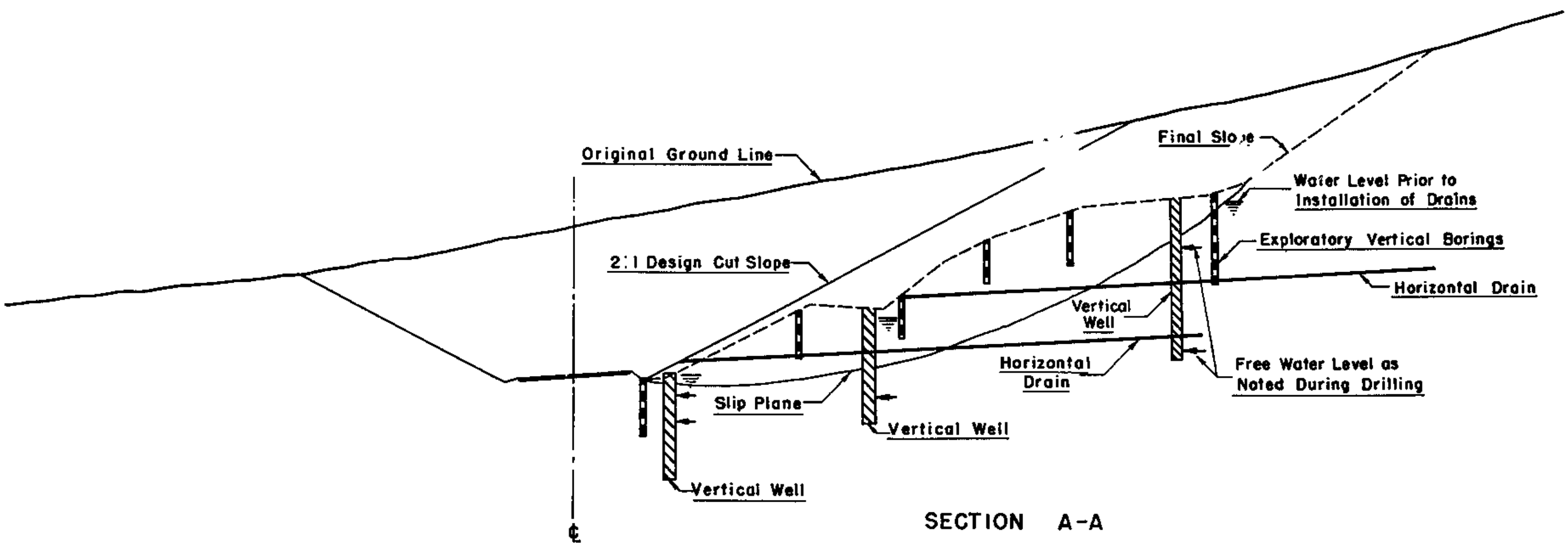

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FIG. 2 SLIDE CORRECTION

HORIZONTAL DRAINS IN COMBINATION WITH VERTICAL DRAIN WELLS

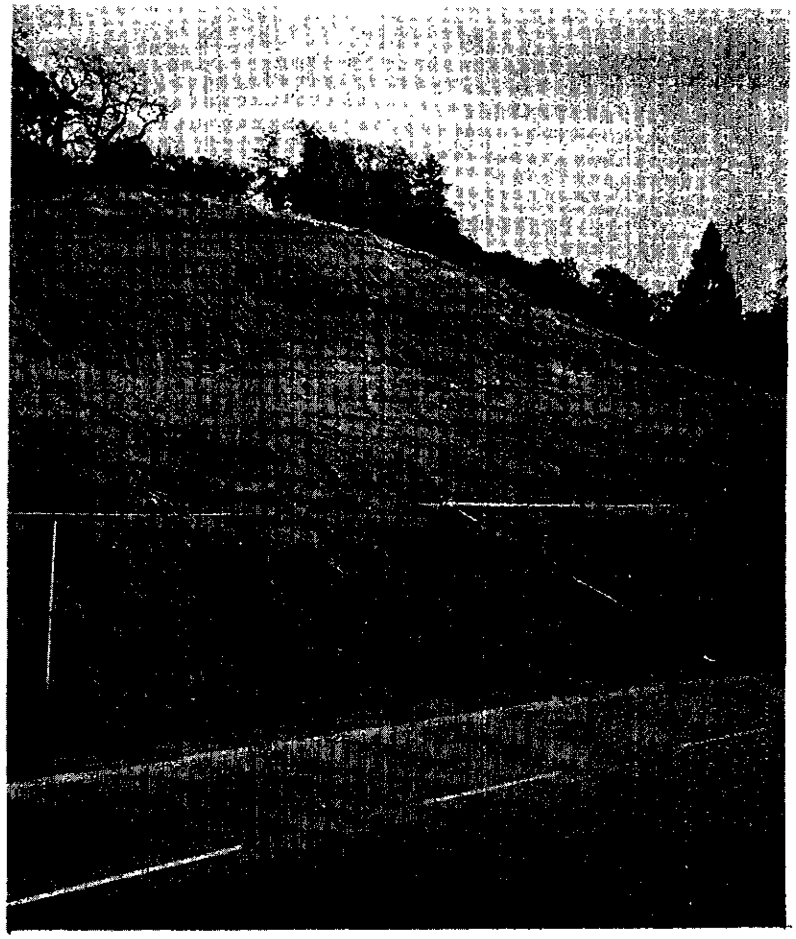


Fig. 3. Slide condition corrected by vertical wells and horizontal drains (See Fig. 1 & 2).

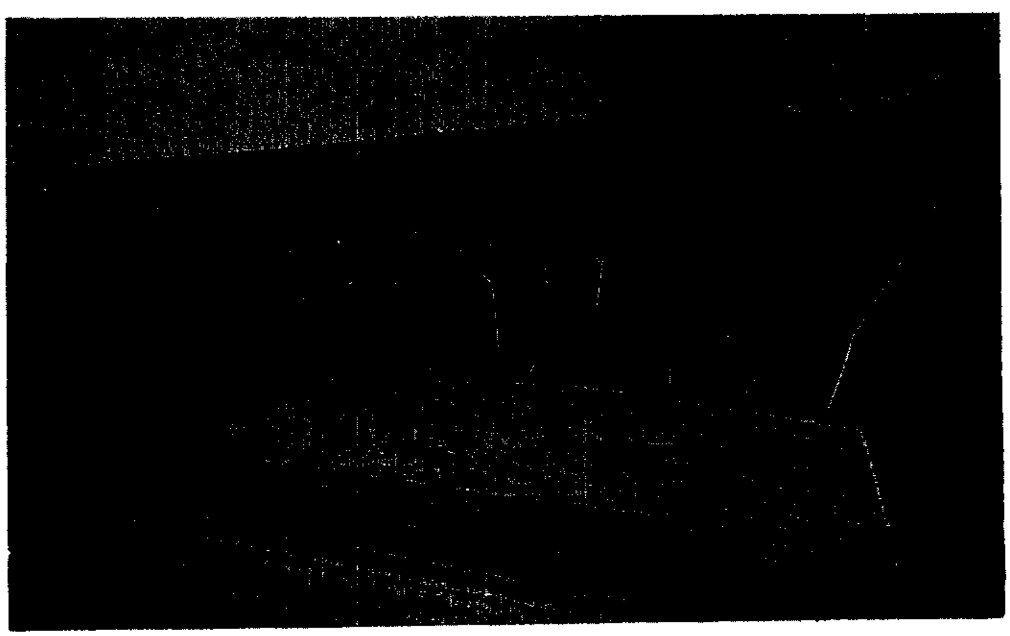


Fig. 4. Completed drain installation and collector pipe system.

reached with the drilling equipment or to which access can be provided. To be serviceable the upper portion of the drain must intercept the subsurface water that is contributing to the unstable soil condition. The drains are usually installed on grades of 3 to 20 percent with 10% being the best working grade. Occasionally steeper or flatter grades are used, but generally they are not practical. There is a tendency to lose or gain grade in the drilling operation. If soil conditions, through which the drilling is done are uniform, the tendency is to lose grade due to weight of the drill rods and bit. Non uniform character of the formation through which the holes are drilled has a great effect on maintenance of grades. The bit will tend to follow the path of least resistance, i.e. to follow fissures, soft layers, or along the contact between layers of material having different drilling characterists.

Caving has proven to be the greatest single difficulty encountered in the installation of horizontal drains. Slide areas are usually composed largely of loose and broken material and the walls of the hole are unsupported while drilling is in progress. Much footage is lost due to the hole collapsing either during drilling or after drilling has been completed, but before the casing can be installed. With modern rock bits it is possible to drill very hard formations, but no satisfactory method of drilling and casing in one operation has yet been devised.

One other important consideration in planning a drain installation is a collection pipe or system to carry the intercepted water out of the critical area. (Fig. 4). If the outlet of the drains discharge into an existing gutter, usually no other steps are taken. If this is not the case, some other means is used. Access is provided at the lower ends of the drains for future inspection and cleaning.

The most satisfactory installation has been the use of 6" to 8" galvanized CMP. The drain outlets are connected to the larger CMP which in turn collects the water from the drains and carries it to any desired location outside the slide area, such as a natural surface channel.

At least two important things should be kept in mind during layout and installation of the collecting pipes:

1. Easy accessibility of the individual drain for future inspection and maintenance is important.

2. Collecting pipe should be anchored in such a way (preferably to drain outlets themselves) that slight slide movement or local sloughing will not cause the collector pipe to move away from the drain outlet and become disconnected.

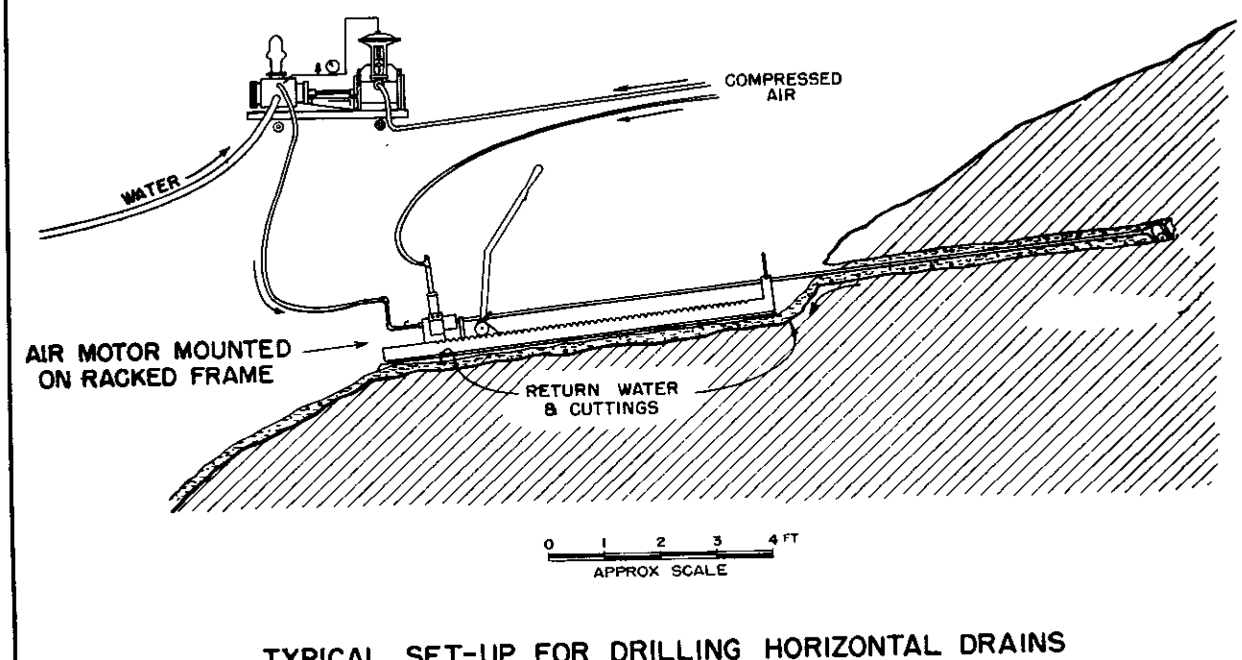
Where freezing may occur during the winter season it may be necessary to bury the collecting systems.

Open flumes and paved ditches have been used for collecting and carrying the intercepted water, but because these two types of collectors require constant inspection and cleaning they have not proven too satisfactory.

Equipment

The first equipment used by the Division of Highways in 1939 for horizontal drilling was "Hydrauger" equipment. (Fig. 5). Hydrauger is a proprietary name for equipment that originally was designed and developed for utility construction work where insertion of pipes under side walks, streets, highways and property was necessary without disturbing the surface.

Fig. 5. Operating Hydrauger equipment.



TYPICAL SET-UP FOR DRILLING HORIZONTAL DRAINS

Fig. 6.

The "Hydrauger" equipment consists of a rotary drill mounted on a racked frame in such a way that a revolving drill bit may be advanced into the earth with a hand operated ratchet lever while water is pumped through the drill rod to cool the bit and wash the cuttings from the borings. (Fig. 6). Five-foot lengths of drill rod are added as the drilling proceeds. Compressed air engines which are quite compact and portable are utilized for pumping water and operating the drills. The compressor and water pump are placed at convenient locations with suitable pipe or hose lines leading to the drilling units. With this arrangement of equipment it is not necessary to move the heavier compressor and pump when moving from the location of one boring to another.

The first horizontal drain holes were drilled by a 2" pilot bit and then reamed to 6" in diameter before casing with 4" PMP. It was soon found that it would be more practical to perform the drilling in one operation. This resulted in the adoption of a 4" modified fishtail bit to do the drilling in one operation.

The 4" modified fishtail bit was progressively improved, beginning with construction out of a good steel followed by facing on the cutting edges with tube borium. The ultimate was reached with this type of bit by using a combination of tungsten carbide inserts and tube borium on the cutting and wearing surfaces for drilling in hard formations.

Various other types of commercially available bits were tried. No better bit was found until 1949 when the rock roller bit commonly used in the oil fields became available in small sizes. (Fig. 7) These bits were tried, proved superior in all formations except possibly stiff plastic clays, and have been used almost exclusively since.

Standard perforated 2" iron pipe with the following specifications is used for casing:

> "Standard 2" black steel pipe perforated with 3/8" diameter holes on 3" spacing drilled in 3 rows at the quarter points, to be furnished in random lengths of 16 to 24 feet without threads or couplings. Pipe to be vertically dipped in a standard pipe dipping asphalt subsequent to drilling."

This casing is butt welded with oxy-acetylene equipment as it is jacked into the hole. The principal purpose of welding the joints together rather than using screw joint couplings is to hold the perforation rows in alignment. The perforations are normally placed up so the intercepted water will be carried out of the critical area to discharge into the collector drain.

The borings are cased by the use of an extra carriage which replaces the drill on the racked frame after the drilling is completed. The casing was originally held in the carriage saddle and kept from slipping by the use of 36" pipe wrenches. This arrangement was later revised and improved by constructing a grip similar to a standard chain pipe vise as an integral part of the carriage.

During the first few years of drain installation work a sharpened wooden plug was driven into the leading portion of casing to serve as a guide with the idea in mind that a retractable folding bit could be used through the casing to drill out an occasional large obstruction caused by caving during the casing operation. Experience indicated that in most cases the wooden plug was merely driven back into the casing and only served the purpose of plugging the end. This did keep soil and

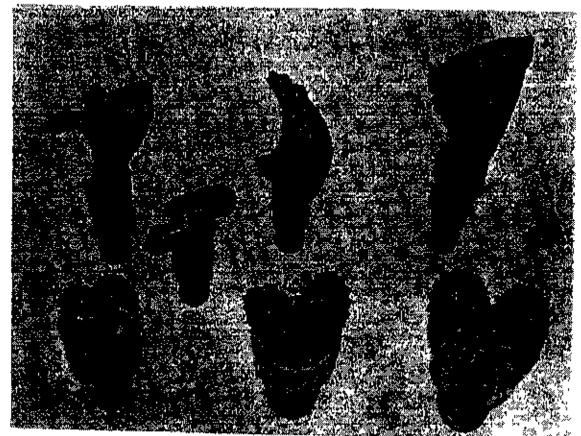


Fig. 7. Bit types past and present used for drilling horizontal drains.

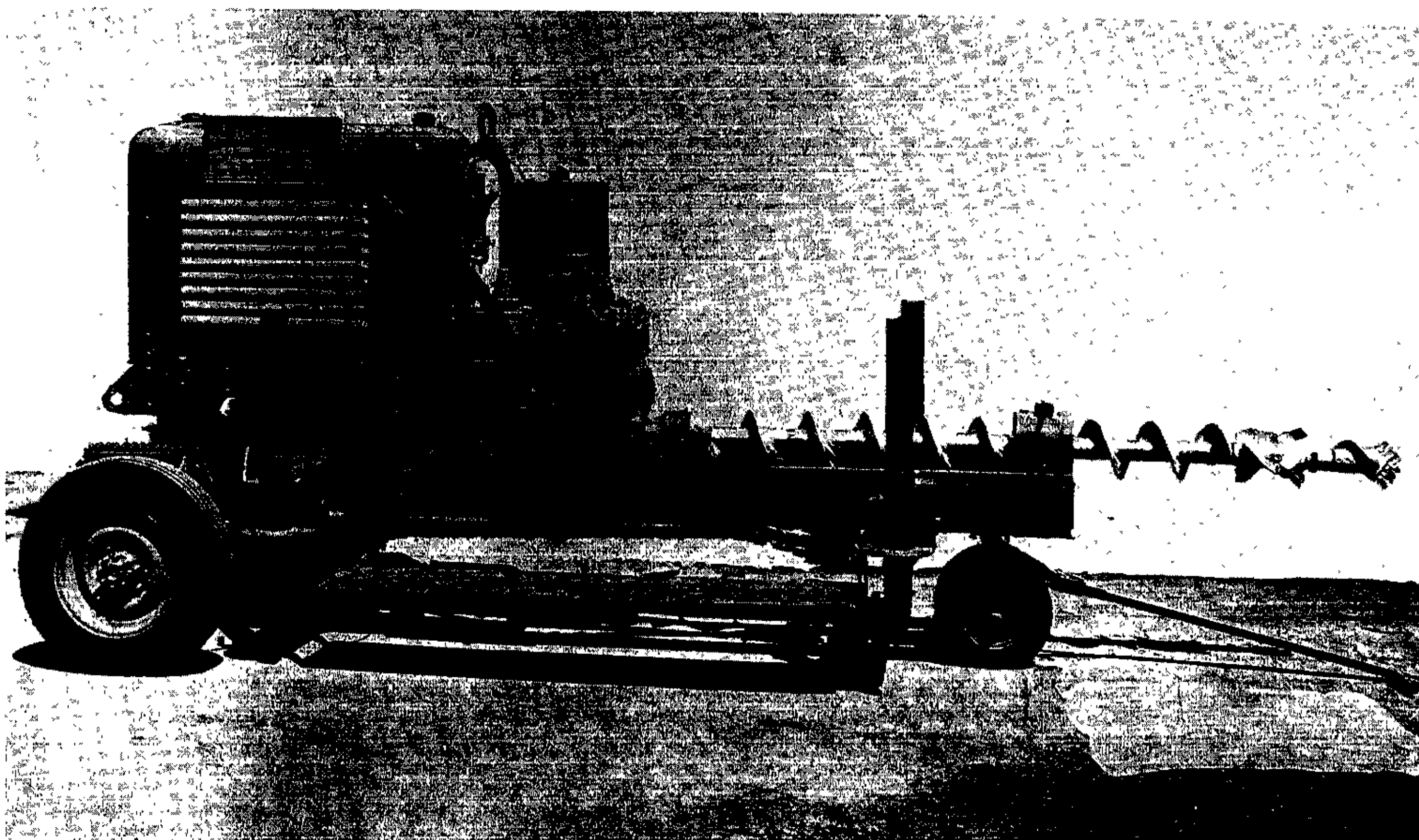


Fig. 8. McCarthy Rock Boring Machine with continuous flight augers.

rocks from entering the casing but drilling out cave-ins did not prove too satisfactory. This procedure was abandoned in favor of pointing the PMP casing itself and rotating, occasionally, to push obstructions out of the way.

With the experience and progress in horizontal drilling technique it was recognized that more powerful drilling equipment should be obtained to supplement the Hydrauger. Consequently a McCarthy Rock Boring Machine was purchased early in 1951.

The McCarthy drill is a self-propelled unit, capable of moving about within limits of a job, having a hydraulic feed, using continuous flight augers and requiring no water for drilling. (Fig. 8). It proved to be a very good rugged piece of equipment, but the continuous flight augers were limited to drilling in soil or soft rock formations. The practical drilling depth, due to lack of directional control caused by the necessary flight coupling arrangement, limitations on power, and strain on the equipment proved to be only about 150 ft. in the formations found in slide areas.

In 1953, two years after obtaining the McCarthy Rock Boring Machine, accessory equipment was fabricated by the California Division of Highways Equipment Department so that regular rotary drilling could be accomplished using diamond drill N-rod and $4\frac{1}{2}$ in. rock roller bits. (Fig. 9). The degree of success upon converting the machine to a rotary type drill led almost immediately to the existing phase of equipment development which can best be described by quoting from the article appearing in May-June issue of "The California Highways and Public Works" magazine by Mr. A. W. Root, Supervising Materials and Research Engineer.

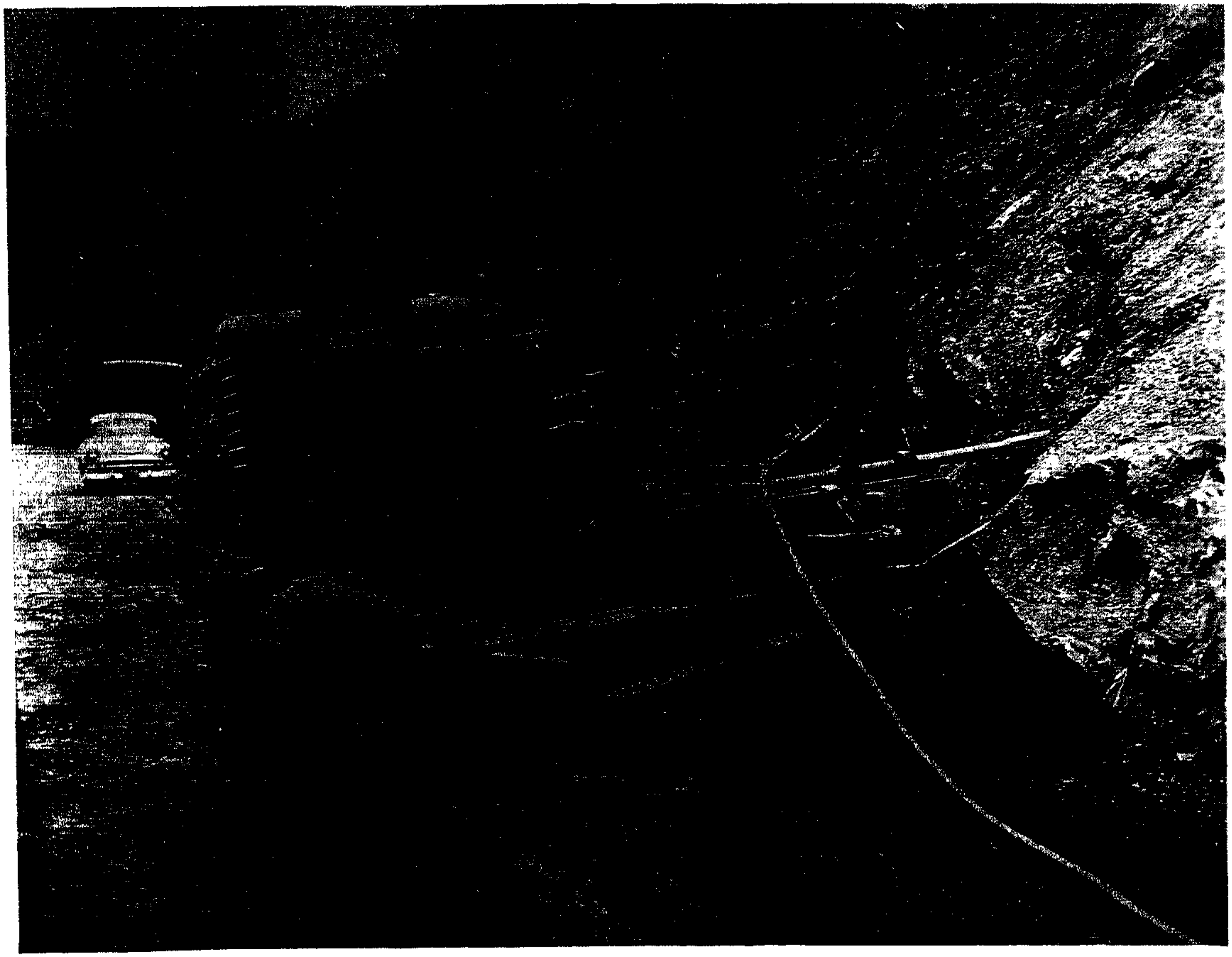


Fig. 9. McCarthy Rock Boring Machine modified to drill with circulating fluid.

"The converted machine operated very satisfactorily, and we found that the use of heavier drill rod, the hydraulic feed and superior power all were advantageous. This machine, however, had one serious drawback: when using the machine for forcing the casing into the drilled hole, the casing must be in front of the drill carriage, as the design of the machine prevents working through a chuck; this necessitates using lengths of casing which can be inserted between the carriage and outlet end of the drain at the ground surface. In restricted working areas it is necessary to use 5 ft. lengths of casing, with a correspondingly large number of field welds. Also the McCarthy machine is somewhat larger and more powerful than necessary for the rotary drilling work on our drain installations, which results in some sacrifice in Mobility.

"<u>Development of Improved Machine</u>

"We could find no drill rig on the market designed specifically for drilling holes for horizontal drains, and none which satisfied our requirements. We desired a drill rig incorporating the following features: The drill unit should be complete with a gasoline engine of adequate power; a suitable transmission to permit control of speed of rotation over a wide range; a hydraulic feed with a minimum stroke of six feet, capable of exerting a 4000-lb. thrust; provision for slowly rotating the casing concurrently with the jacking operation when necessary; a chuck readily interchangeable for A-rod, N-rod or casing and so designed that long lengths of rod or casing can be operated through the chuck; rugged, but easily operated spuds for maintaining alignment and grade of the drill; rubber-tired wheels and three-point suspension to permit sharp turns; and, finally the overall length not to exceed twelve feet and the weight of the complete drill to be not more than 3000 lbs.

"The Materials and Research Department had for several years realized the need for such an improved horizontal drill, and as no completely suitable machine could be purchased, it was decided to design and build a drill unit specifically for horizontal drilling. Accordingly, the Equipment Department was requested to design and build a machine meeting the specifications outlined above. By March 1954 the final drawings had been completed for a machine having the desired features and meeting our specifications; on June 30 the Shop had completed its construction. (Fig. 10). The new drill rig, for the most part, is comprised of standard or proven parts of sub-assemblies similar to those used in manufactured drills. The machine is unique because it incorporates the desirable features of various machines into a light-weight, compact drill rig especially suitable for the type of drilling required for installation of horizontal drains. The power unit is a 20 HP Wisconsin 4-cylinder, air-cooled engine, connected through a fluid drive to a 4-speed Ford transmission, Rotation of the chuck is accomplished by a gear train from the transmission enclosed in an oil-tight housing. The entire drive assembly is mounted on a hydraulically operated carriage with a travel of six feet. A Vickers ten-gallon-per-minute oil pump, driven by the Wisconsin engine, supplies oil to two hydraulic cylinders, by means of which the thrust can be controlled at any desired feed pressure up to 4000 lbs.

"A specially designed chuck assembly was required to permit the use of long lengths of drill rod or casing, and to provide for interchanging chucks for different size rods. Standard

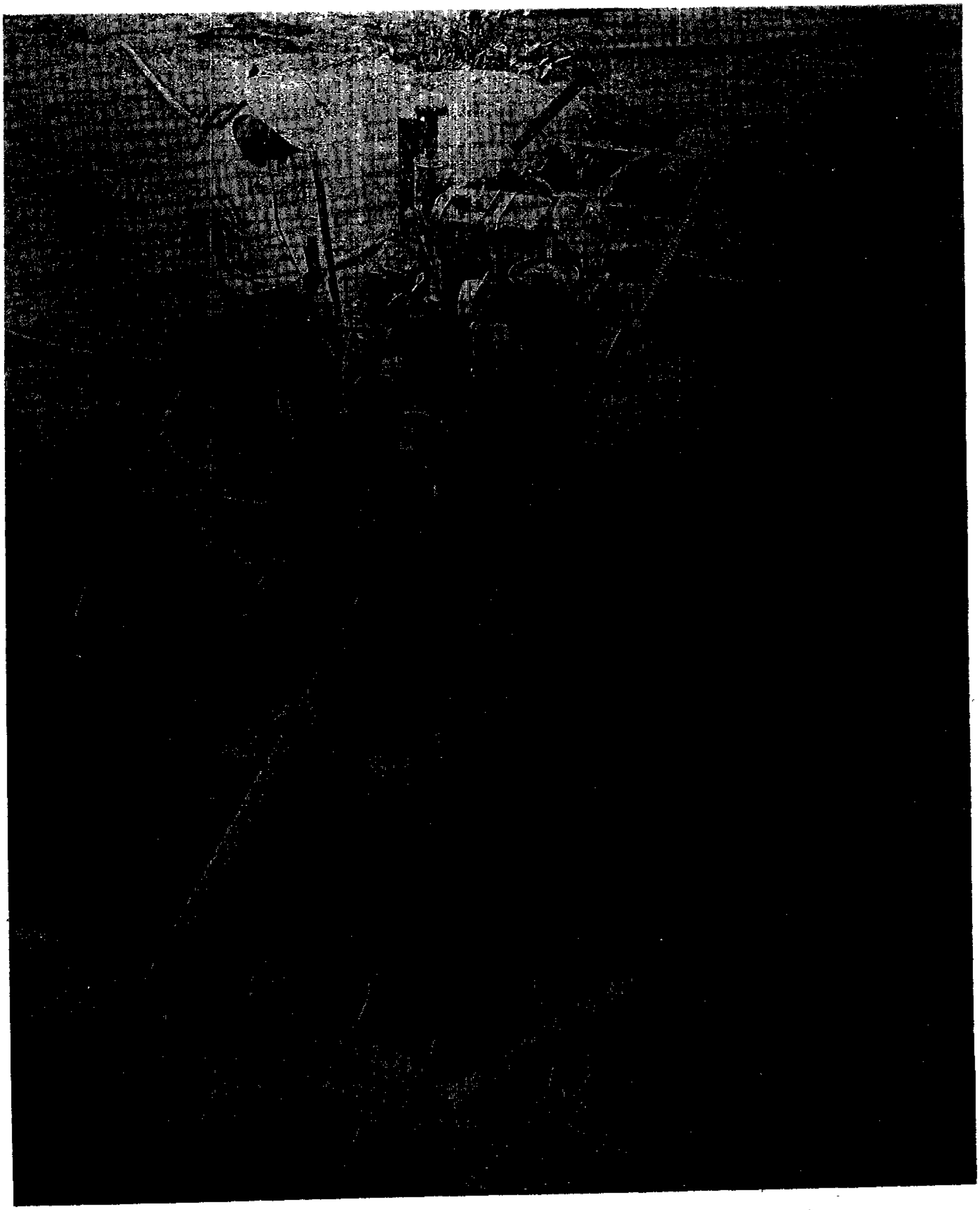


Fig. 10. California horizontal drill rig in operation.

A-rod and N-rod chuck heads are used, with a shop-designed chuck holder which permits quick change of chuck heads. A special chuck for gripping the two-inch casing is used in the same chuck holder."

While the horizontal drilling equipment has gone through several stages of development, the development has usually resulted from particular needs dictated by drilling conditions encountered. This is borne out by the fact that while we have just recently built this California Horizontal Drill to our own specifications, and feel that it is definitely superior in many respects to other available equipment, we still retain several Hydrauger units essentially as they were modified originally in 1939 for our horizontal drilling. These light portable units still have the advantage of greater mobility where access and set-up room is a problem.

Maintenance

Some maintenance of horizontal drain installations is necessary if they are to continue to be effective for long periods of time. The maintenance required is dependent upon local soil conditions, vegetation, rainfall, road conditions, and other factors.

Considerable maintenance has been eliminated by the use of approximately 20 lineal feet of non-perforated galvanized pipe for the last length of casing placed in the boring. This, in most cases, minimizes trouble from root growth in the casing and retards corrosion at the outlets. (Fig. 11). Aside from regular inspection and repair of visible damage and obstructions the major maintenance consists of cleaning at intervals of three to ten years to remove root growth, corrosion, and soil from

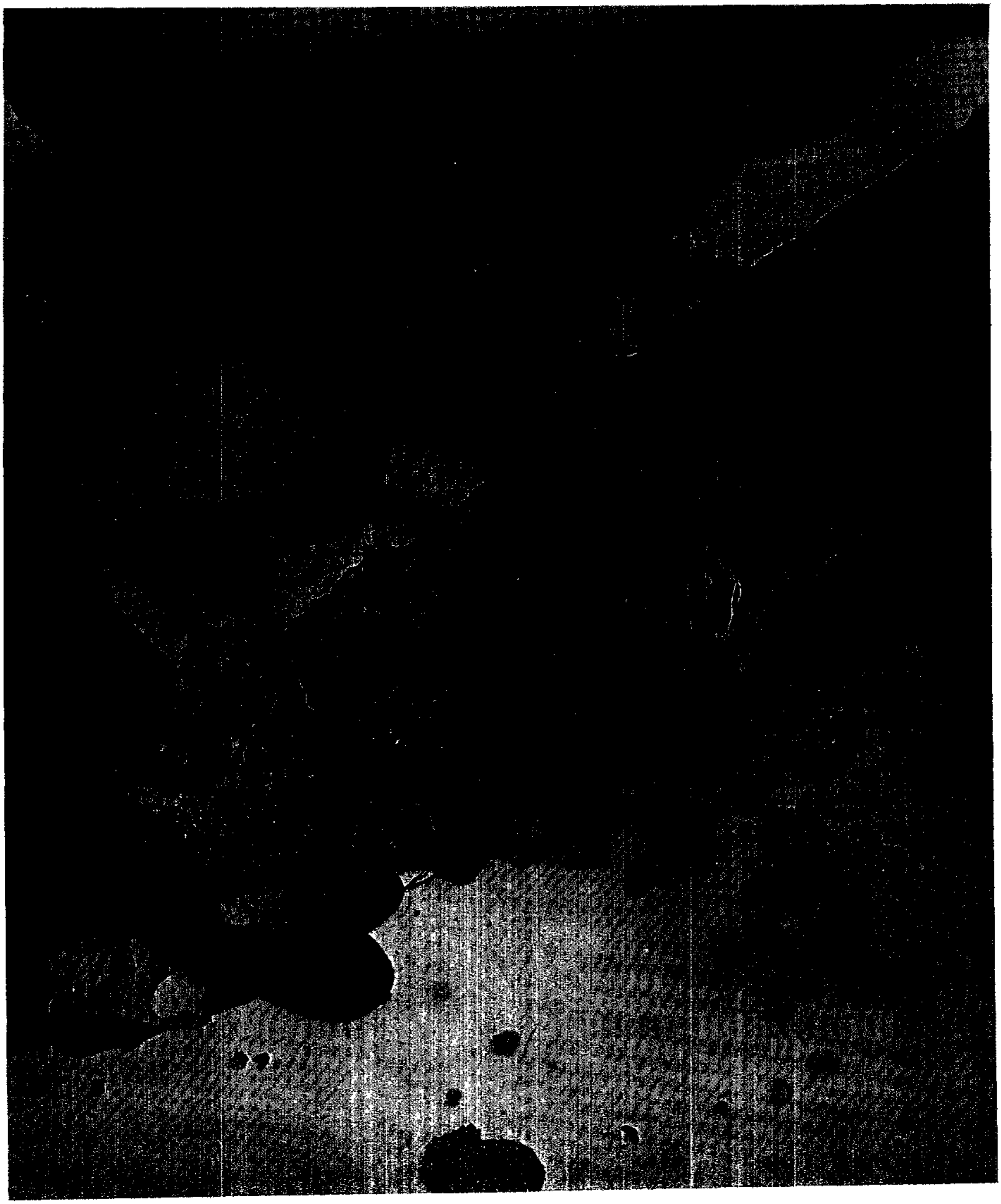


Fig. 11. Extreme case of root growth in horizontal drain.

drains.

It is important that the drains be cleaned thoroughly when their efficiency has been impaired. This, in the great majority of cases, restores them to their original effectiveness.

While limited cleaning may be done with hand tools the only satisfactory method has been with the use of power equipment. This is usually accomplished with the original installation equipment modified for this purpose or with a relatively light hand-held air motor similar in operation to the Hydrauger machine. Diamond drill E-rod with an auger type bit small enough to rotate freely in the casing is used for the drilling tools. Some of the water jets of the cleaning bits are so directed that the casing is thoroughly washed and flushed as the bit progresses through the casing. Water delivered to the air motor at 150 psi to 200 psi has proven adequate. Standard practice has been to clean the drains to a 50 ft. minimum depth or 10 ft. beyond the point where the flushing water becomes clear when greater cleaning depths are necessary.

The chief advantages of machine cleaning operations are:

1. Drains may be cleaned to much greater depths than by hand.

2. Cutting out the root growth entering the casing perforations is more complete.

3. Vibration as a result of machine operation of cleaning tools combined with adequate pressure and volume of the flushing water tend to loosen and wash out rust, scale, soil any any other deleterious material which may be in the casing or its perforations.

4. Vibration also tends to agitate soil adjacent to the

casing, allowing larger flow of subsurface water into casing.

It has sometimes been necessary to replace the outlet ends of the casing where rusting and corrosion have caused excessive damage to the "stickout." Galvanized pipe is always used for this replacement. No replacement to date of this portion of the drain has been necessary where a length of galvanized pipe was used for the outlet end in the original installation.

Effectiveness

Drain installations that have been preceded by adequate investigation and that are properly planned have usually been effective in removing subsurface water and this in turn has corrected or improved the unstable condition.

Drain installations have been most effective in areas where the subsurface water could be intercepted in well defined acquifers or layers, where these layers were sufficiently permeable to permit ready removal of the water, and where these layers could be reached with holes not more than 300 feet long on 10 to 15 percent grades through formations that can be drilled successfully and the borings do not cave.

Some installations made with as few as eight to ten drains, all less than 100 feet in length, have been effective in correcting a slide. Other installations have required in excess of one hundred drains, some of which were drilled to the maximum practical depth.

Perhaps the two types of foundations in which it is most difficult to make installations are (1) silty fine sands that tend to erode or wash badly during the drilling operation and cave to the extent that casing the holes is difficult; and (2) hard broken formations that are difficult to drill. In this type of material loss of circulating fluid is a problem, as well as the caving during drilling and casing operations. Competent drilling personnel are a must in the installation of drains and this is certainly emphasized when drilling or casing operations are difficult.

The quantity of water that is produced or drained at the time of installation may not be a good measure of the flow that will occur later or of the effectiveness of the installation. Some drains may produce large flows during the rainy season or during and after actual periods of rainfall, and be dry or produce very little water at other times. Other drains may produce flows that vary somewhat with the seasons yet are relatively constant. It is also true that in some instances the removal of a relatively small quantity of subsurface water will produce a stable soil condition, whereas other instances may require the removal of very large quantities of water to produce the desired results.

<u>Summary</u>

It is the opinion of the writers, based on their experience and the experience of other personnel in the Materials and Research Department of the California Division of Highways that:

1. Installation of drains should be preceded by investigation and planning by competent engineers with thorough knowledge of soils and geology.

2. The actual installation should be made by trained personnel who are proficient in this type of work.

3. Much progress has been made in the development and utilization of available equipment, but there is still a large field for development in this direction.

4. Systematic inspection and maintenance is a vital part of the overall program of an effective horizontal drain installation.

5. Horizontal drains have a definite place in the correction and prevention of slides in the design, construction and maintenance of embankments and cuts, and when properly planned, installed and maintained they are effective.

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